Lycopene Content Among Organically Produced Tomatoes

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ABSTRACT. There is little information on how organic production methods affect phytonutrient content of tomato (*Lycopersicon esculentum* Mill.). This project was undertaken to determine how much lycopene was produced in tomatoes grown organically, and if tomatoes picked at the breaker stage could obtain full lycopene content. 'Classica', a Roma type of tomato, was highest in lycopene (106 mg·kg^{-1}) and the other cultivars had 50-60 mg·kg^{-1} lycopene in soft red fruit. About 50% of the total lycopene found in soft red tomatoes was present in pink tomatoes and 70% in light red fruit. Fruit picked at unripe stages (breaker through

light red) gained as much or more lycopene as those picked firm or soft red. Tomatoes grown organically contained substantial amounts of lycopene when ripened to firm red or soft red stages. doi:10.1300/ J484v12n04_07 *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@ haworthpress.com> Website:<http://www.HaworthPress.com> © 2006 by The Haworth Press, Inc. All rights reserved.]*

INTRODUCTION

Tomatoes contain lycopene, a carotenoid believed to help prevent cardiovascular disease and certain cancers. Dietary lycopene is associated with reduced incidence of cardiovascular disease and some cancers, notably prostate cancer (Giovannucci et al., 2002; Giovannucci, 1999).

The demand for organically grown vegetables, including tomatoes, continues to increase annually in the U.S. market (Plotto and Narciso, 2006). One of the most common requests of organic growers is to evaluate cultivars for suitability in organic production systems. Many tomato varieties for fresh market exist, including determinate types (no staking needed), indeterminate types, and heirloom varieties prized for their perceived flavor. Selection of a suitable cultivar for organic production must include special attention to the tolerance of the cultivar to the local environment, such as disease tolerance in areas of high rainfall, and adequate foliage to protect fruit from sunburn in areas,where air temperatures and light intensity are high.

Tomato cultivars and genotypes vary greatly in lycopene, with processing types or those containing the crimson (*og*) gene generally higher in lycopene than salad or normal types (Dumas et al., 2003). The lycopene content of tomatoes sampled in the U.S. averages 3.6 mg/100 g (USDA, 2005), and is based on fruit samples taken at retail markets over the four seasons in a year. Several commercial ripeness charts are used in the U.S. to separate tomato ripeness stages (Kader and Cantwell, 2004). The most commonly harvested stages of field grown tomatoes are mature green, breaker, turning, and pink fruit, which are ripened in storage rooms before retail distribution. In contrast, tomatoes grown in home gardens, or for farm stands, are harvested between pink and soft red stages of color. Thompson et al. (2000) reported that tomatoes har-

vested in Florida at breaker stage reached maximum lycopene content after six days at room temperature, while Arias et al. (2000) found that greenhouse tomatoes ripened on the vine had 32% less lycopene than those ripened off the vine.

The purpose of this research was to determine how much lycopene was produced in tomatoes grown organically, and if fruit picked at early color stages would reach a lycopene content similar to that of the fully ripe tomatoes.

MATERIALS AND METHODS

Plant material. Tomatoes of 13 commercial fresh market varieties were grown in certified organic field at Lane, OK in 2005. Varieties selected for trials were of a fresh market type, and were round beefsteak types except for 'Classica', a Roma style tomato. Beds were formed in Bernow silty loam soil amended with organic poultry litter (about 2-2-2 N, P_2O_5, K_2O) at rates of 6.7, 5.6, 4.5, and 4.5 Mt. Plants were transplanted on October 21, 2003 and April 6, 2004, respectively, in beds on 2.7 m centers with 0.9 m between plants. Three blocks per cultivar were randomized across the field. Water was applied as needed using drip irrigation. Fruit were randomly harvested across plots at the breaker, turning, pink, light red, firm red, and soft red stages of fruit color (Kader and Cantwell, 2004) at 3 to 7 days intervals. Tomatoes were selected to be free of defects due to insects, disease or cracks. For ripening studies, tomatoes were placed at random on metal trays and held until soft red at 25-29°C, 75-80% R.H., under fluorescent and indirect lighting.

Quality assays. All fruit were weighed and maximum diameter measured with digital calipers to 0.1 mm (Mitutoyo, Daigger Lab Supplies, Vernon Hills, IL). Color was measured at two opposing sides of the equatorial region per tomato with a chromameter (Minolta CR200, Konica-Minolta, Ramsey, NJ), using an 8 cm aperture, D_{65} color space, and CIE L*a*b*. Hue (degrees) and chroma were calculated using the formula $\tan^{-1} (b/a)*57.3$ and $[(a2) + (b2)]^{1/2}$, respectively.

A cross section slice (about 1.2 cm thickness) was cut about one cm from the middle of the tomato, cut in quarters, placed into plastic bags, and frozen at $-20°$ C for further analysis. Two quarter slices were partially thawed then individually pureed per fruit as duplicate samples, using a blender cup and homogenizer (Polytron, Brinkman, Westbury, NY). Water was added at a 1:1 wt/wt prior to pureeing. Samples of 50 mL puree was collected for each duplicate. Lycopene was determined

using a Hunter color scan analyzer (Davis et al., 2003) and by spectro-photometric determination (Fish et al., 2002) in a ratio of 2:2:1 hexane: ethanol:acetone solvents (10:10:5 mL) (Pharmco, Brookfield, CT). Sol-uble solids were analyzed by placing 0.5 mL of puree on a digital re-fractometer (Atago, model PR100, Gardiner, NY) and pH determined on tubes of puree using an Orion 8100 electrode.

The cultivar comparison of fully ripe fruit was a completely random-ized design using 13 cultivars. A total of 10 fruit at the soft red stage/ cultivar were used. The comparison of ripeness stages was a factorial design of 12 cvs × 4 ripeness stages. The storage study was a factorial design of 12 cvs × 6 ripeness stages. A total of 10 fruit/cultivar and ripe-ness stage were used for the storage study, and an additional 10 fruit/color stage and cultivar were used for pink, light red, and firm red compari-sons to soft red fruit (not stored). 'Classica' was omitted from storage and color studies. Data were subjected to SAS, v. 9.0, Cary, NC, using a general linear means model. Means were separated with the Ryan-Einot-Gabriel-Welsch multiple F test. Correlations were performed using Pear-son's Correlation Coefficient analysis.

RESULTS AND DISCUSSION

Cultivar differences among fully ripened fruit. 'Classica' had a lesser fruit weight and smaller diameter, compared with the round (beefsteak) types (Table 1). 'Florida 91' had the largest fruit of the beefsteak types. The pH of purees from tomato cultivars was similar (4.2 to 4.4, data not shown). The soluble solids content (SSC) varied slightly, from 4.3 to 5.2, among the cultivars. Thompson et al. (2000) found a slight differ-ence in soluble solids and pH among red fruit of nine tomato selections, with values similar to those reported in our study.

Lycopene content was highest in 'Classica' (106 mg·kg^{-1} average) and ranged from 50 to 61 mg·kg^{-1} in the other cultivars (Table 1). Roma and processing type tomatoes traditionally contain more lycopene than the larger beefsteak types, due in part to the smaller diameter and sub-sequently higher peel and pericarp ratios, and to the higher solids (nonwater-soluble) content. On a per unit weight basis, lycopene is high-est in the epidermal peel and pericarp (Shi and Le Maguer, 2000).

Among the remaining cultivars, the range of lycopene in soft red fruit was 50 to 61 mg·kg^{-1}, considerably higher than those reported in the USDA database. Fruit sampled for the database are sampled from retail markets over seasons at four to six locations across the U.S., and were

TABLE 1. Comparison of fruit size and composition among 13 tomato cultivars when harvested fully ripe (soft red) grown using organic production methods.

Cultivar	Fruit weight (g)^z	Fruit diameter (mm)	Soluble solids content (%)	Total lycopene (mg·kg^{-1} fwt)	L*	a*	b*	Hue (°)	Chroma
Amelia	226.8abcd	73.2b	4.3b	53.7b	44.1a	23.8bcd	26.6ab	47.8ab	35.8ab
BNH-44	219.1abcd	73.2b	4.5b	59.5b	44.1a	23.3bcde	21.428	42.6abc	31.6bc
Celebrity	306.2abc	94.0a	4.6b	57.4b	43.8a	21.6de	24.6ab	48.6a	33.0abc
Champion	157.3de	72.8b	5.1a	51.7b	43.8a	24.4bcd	27.9a	48.4a	37.1a
Classica	115.4e	48.1c	5.4a	106.5a	43.0a	28.2a	24.3ab	40.7c	37.2a
Florida 47	242.7abcd	80.4ab	5.0a	55.1b	48.8a	25.4abc	23.1ab	42.2abc	34.4abc
Florida 91	334.1a	89.4ab	4.3b	49.9b	44.1a	24.1bcd	26.5ab	47.5ab	35.9ab
Mountain Delight	235.5abcd	79.5ab	4.7ab	57.4b	43.3a	25.0abcd	27.9a	47.7ab	37.6a
Mountain Fresh	326.0ab	86.7ab	4.6ab	61.1b	42.6a	26.4ab	23.8ab	41.9bc	35.6ab
Mountain Spring	211.6cde	75.7b	5.1a	55.3b	44.6a	24.2bcd	25.5ab	46.3abc	35.2ab
Peron's Red	213.3cde	79.4ab	5.2a	49.5b	44.3a	20.2e	22.231	47.4ab	30.2c
Solar Set	245.8abcd	78.4ab	4.9ab	61.2b	43.8a	22.26cde	23.2ab	45.7abc	32.6abc
Sunmaster	233.6abcd	76.8ab	4.6ab	60.0b	43.6a	24.8b	24.0ab	43.8abc	34.6abc

^{z} Values within columns with the same letter are not significantly different, $P \leq 0.05$, REGWQ.

usually picked at breaker or mature green stages and ripened in low light rooms. In our study, fruit were freshly harvested and exposed to high levels of light during field ripening, which may have increased the phytochrome activity in the skin, and increased subsequent lycopene values (Alba et al., 2000). 'Champion', the only indeterminate tomato type used in this study, was subjected to pruning during growth to eliminate suckers. The hot, dry conditions in 2005 (mean 38/32°C max/min) resulted in poor foliage growth in this cultivar, and subsequent solar injury through tissue overheating (Lipton, 1970) on many of the fruit. Lycopene values of 'Champion' were not reduced compared to other cultivars as sunburned fruit were discarded. The high incidence of sunburned fruit in the field (about 20%) indicates that 'Champion' was not a suitable cultivar for organic production under conditions at Lane, OK.

The lightness of the tomatoes was not significantly different among cultivars (Table 1), although 'Classica' had the darkest (lowest L*) and 'Florida 91' the highest values. The a* value, the red/green component, was highest for 'Classica' and b* was highest for 'Classica', 'Mountain Delight', and 'Champion' (most orange-red) and lowest for 'Peron's Red' (most blue-red). A hue angle of 90° indicates a yellow color, while 45° indicates orange-red (Kabelka et al., 2004). 'Celebrity' was highest in hue and lowest in chroma, indicating the most orange red but least intense color; 'Classica' was lowest in hue and high in chroma, indicating a more intense red color than the other cultivars. In contrast, the high chroma and hue of 'Champion' indicates a more intense orange-red than the other cultivars.

Effects of ripeness on tomato composition. Fruit picked at pink stages were slightly smaller in size (weight and diameter) and slightly lower in pH than soft red fruit (Table 2). Soluble solids content (SSC) did not change significantly among ripeness stages. Soluble solids content is a combination of sugars, nonvolatile organic acids, and soluble cell wall components. Reducing sugars contribute 75 to 80% of the SSC in tomatoes (Kader et al., 1977). Betancourt et al. (1977) found that fully ripened fruit held on the vine had more reducing sugars than those harvested at the breaker stage and ripened off the plant. In our study, a loss in reducing sugars may have been offset by an increase in cell wall components, resulting in no change in the soluble solids content.

Visible color, measured as changes in red, green, and yellow, increased in red value (a*) and decreased in yellow (b*) as fruit ripened (Table 2). Lycopene content in pink fruit was about 50% of that of soft red fruit (Figure 1), increasing to 70% of the total lycopene content in

TABLE 2. Compositon of tomato fruit grown using organic production methods harvested at different color (ripeness) stages.

Color stage	Whole fruit weight (g)	Fruit diameter (mm)	SSC (%)	pH	Minolta colorimeter color values						Total lycopene (mg·kg^{-1} fwt)
					L	a*	b*	Hue (°)	Chroma	a/b	
Pink	208.5c^Z	76.7b	4.7a	4.27c	54.3a	11.5c	28.8a	68.7a	31.4c	0.40d	29.0c
Light Red	236.5ab	80.6a	4.8a	4.28bc	48.6b	19.9b	28.0a	54.8b	34.6b	0.72c	40.4b
Firm Red	220.6bc	79.9a	4.7a	4.30b	44.8c	24.2a	26.2b	47.1c	35.7a	0.94b	55.5a
Soft Red	245.2a	80.3a	4.7a	4.33a	43.8d	23.8a	24.5c	45.5d	34.2b	1.00a	56.1a

^{Z} Values within columns with the same letter are not significantly different, P ≤ 0.05, REGWQ.

FIGURE 1. Percentage of total lycopene (based on 100% in soft red fruit) in tomatoes harvested at different color stages.
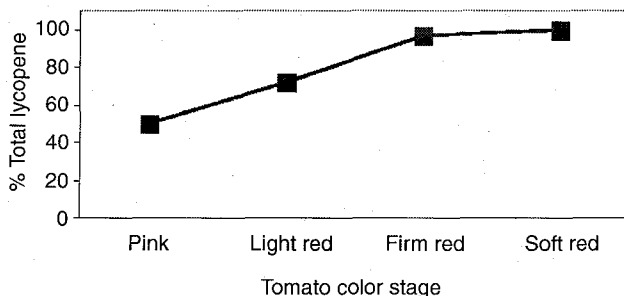
light red fruit. Fruit harvested firm red were not different in lycopene content from soft red fruit.

Lycopene was most closely correlated with the color variables lightness, hue, a*, and a*/b* (Table 3). When regressed, a linear relation yielded a fit of 0.46 to 0.51 R^2 for hue and a/b (Figure 1A and B). The ratio of a*/b* or of (a*/b*)^2 is often used as a quick indicator of ripeness in tomatoes when separating green to red stages.

Effects of storage on ripening of tomato fruit. Fruits that were harvested at breaker or turning stages were smaller than those harvested at later stages of ripeness (Table 4). However, fruit harvested before full redness developed color and lycopene content similar to, or exceeding, those harvested soft red. Weight loss was greater from the less ripe fruit, due to the longer time period needed to ripen fruit. The increased lycopene content of these fruit may be due in part to a concentration effect from weight loss.

Colorimeter values for tomato skin color following ripening showed little correlation with lycopene. Where fruit were harvested and measured for color and lycopene immediately after harvest (pink to soft red), a strong linear relationship was seen between skin color (hue or a*/b*) and lycopene value (Figure 2A and B). This relationship is similar to that reported by those working with green to red fruit. In contrast, the relationship was poor when fruit were picked unripe and then allowed to reach full ripeness before color and lycopene were measured, or when only soft red fruit were used to plot color values against lycopene content. The difference in results between red fruit and those measured with green color indicates that the chromameter we used was not sensitive enough to effectively predict lycopene values over 20 mg·kg^{-1}.

TABLE 3. Correlations[z] among variables of tomatoes harvested at pink through soft red stages, day 0.

|	Diameter	SSC	pH	Lycopene	L	a*	b*	Hue (°)	Chroma	a/b
Fruit weight	0.74**	0.05	0.03	0.09	−0.06	0.09*	−0.02	−0.08	0.05	0.08
Diameter		0.03	−0.03	0.08	−0.07	0.12**	−0.01	−0.11*	−0.08	0.10*
SSC			0.13**	0.21**	−0.02	−0.01	−0.07	−0.02	−0.07	0.03
pH				−0.16**	0.11*	−0.15**	−0.15**	−0.15**	−0.03	0.16**
Lycopene					−0.89**	0.73**	−0.28**	−0.76**	0.33**	0.76**
L						−0.89**	0.26**	0.90**	−0.44**	−0.89**
a*							−0.10*	−0.91**	0.63**	0.88**
b*								0.46**	0.69**	−0.52**
Hue (°)									−0.29**	−0.99**
Chroma										0.24**

[z]*, ** Significance at $P \leq 0.05$, 0.01 levels, respectively, Pearson's correlation coefficient.

TABLE 4. Quality composition of tomatoes harvested at breaker through soft red stages, then allowed to ripen to the soft red stage.

Stage	Fruit weight (g)^z	Fruit diameter (mm)	Weight loss (%)	Soluble solids content (%)	pH	Lycopene	L	a*	b*	Hue (°)	Chroma	a/b
Breaker	182.2c	71.1b	3.4a	4.9a	4.31a	68.2a	43.2b	26.3a	25.3a	43.9b	36.6a	1.04
Turning	199.5c	72.5b	2.9ab	4.8a	4.33a	67.6a	43.4ab	25.7ab	24.6a	43.6b	35.6ab	1.05
Pink	221.8b	75.9ab	2.1ab	5.3a	4.32a	63.4b	43.5ab	26.2a	25.0a	43.6b	36.3a	1.06
Light red	255.2a	86.3a	1.6b	4.7a	4.34a	62.8bc	44.1a	25.3b	25.4a	45.1a	35.9a	1.01
Firm red	255.8a	80.1ab	1.7b	4.8a	4.33a	62.6bc	43.8ab	24.3c	24.9a	45.6a	34.8bc	0.99
Soft red	236.0ab	77.7ab	–	4.8a	4.33a	59.9c	43.7ab	23.8c	24.8a	45.8a	34.5c	1.05

^{z} Values within columns with the same letter are not significantly different, $P \leq 0.05$, REGWQ.

FIGURE 2. Regression of total lycopene content to chromameter values of hue (A) and a*/b* (B) in fruit harvested at pink to soft red stages (not ripened). Outliers represent 'Classica' (Roma-type) tomatoes.
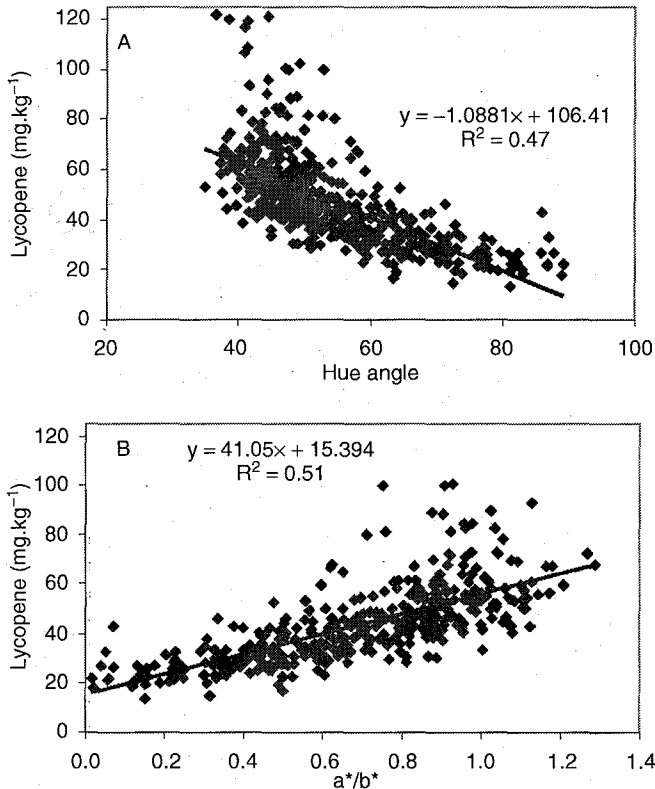
Soluble solids content and pH were similar in pink to soft red fruit at time 0, while lycopene content doubled from pink to firm or soft red stages, over 3 to 8 days, depending on cultivar. Similar changes in lycopene content with ripeness stage have also been reported by Thompson et al. (2000) and Brandt et al. (2006).

While lycopene content was highly and positively correlated with the colorimeter values for hue and a* in fruit harvested at pink through soft red stages (Table 3), this relationship had poor correlations in fruit harvested at breaker to firm red stages then ripened to soft red (Table 5).

TABLE 5. Correlations[z] among variables of tomatoes harvested at breaker through soft red stages, after ripening all fruit to soft red.

	Weight loss (%)	Diameter	SSC	pH	Total lycopene	L	a*	b*	Hue (°)	Chroma	a/b
Fruit weight	−0.28**	0.40**	0.0	−0.08	−0.37**	0.11**	0.01	0.07	0.14**	0.05	−0.03
Weight loss (%)		−0.15**	0.0	0.19**	0.23**	−0.08*	0.13**	−0.015	−0.13**	0.06	0.13
Diameter.			−0.1	−0.1	−0.22**	0.04	−0.003	0.04	0.08*	0.02	−0.02
SSC				0.0	0.13**	−0.005	0.02	0.01	−0.01	0.02	0.02
pH					0.29**	−0.02	0.06	−0.04	−0.13**	0.02	0.08*
Total lycopene						−0.10**	0.18**	−0.05	−0.29**	0.11**	0.20**
L							−0.07	0.26**	0.36**	0.06	−0.21**
a*								0.20**	−0.49**	0.93**	0.83**
b*									0.61**	0.54**	−0.38**
Hue (°)										−0.14**	−0.81**
Chroma											0.57**

[z] *, **Significance at $P \leq 0.05$, 0.01 levels, respectively, Pearson's correlation coefficient.

When regressed, the relationship of lycopene to a* or hue was at best quadratic, with a relative fit of 0.15 or 0.35 (data not shown).

When values for lycopene and hue were regressed, it was apparent that hue reached a maximum value well before lycopene content peaked, indicating that care must be taken in using standard chromameter values to predict lycopene content.

Organically grown tomato fruit were able to fully color and gain in lycopene even when harvested at the onset of color break. Values for lycopene content were higher than those reported in the U.S. Nutrient database, probably because fruit were exposed to high light intensity in the field, and were held for a relatively short time at warm temperatures during post harvest ripening periods. The Roma type tomato was much higher in lycopene than the beefsteak types sampled. Results indicate that fruit could be harvested well before full visible red color without loss of lycopene.

LITERATURE CITED

Alba, R., M. M. Cordonnier-Pratt, and L. H. Pratt. 2000. Fruit-localized phytochromes regulate lycopene accumulation independently of ethylene production in tomato. Plant Physiol. 123:363-370.

Arias, R., T. C. Lee, D. Specca, and H. Janes. 2000. Quality comparison of hydroponic tomatoes (*Lycopersicon esculentum*) ripened on and off vine. J. Food Sci. 65: 545-548.

Betancourt, L. A., M. A. Stevens, and A. A. Kader. 1977. Accumulation and loss of sugars and reduced ascorbic acid in attached and detached tomato fruits. J. Amer. Soc. Hort. Sci. 102:721-723.

Brandt, S., Z. Pek, E. Barna, A. Lugasi, and L. Helyes. 2006. Lycopene content and colour of ripening tomatoes as affected by environmental conditions. J. Sci. Food Agric. 86:568-572.

Davis, A. R., W. Fish, and P. Perkins-Veazie. 2003. A rapid hexane-free method for analyzing lycopene content in watermelon. J. Food Sci. 68:328-332.

Dumas, Y., M. Dadomo, G. Di Lucca, and P. Grolier. 2003. Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. J. Sci. Food Agric. 83:369-382.

Fish, W., P. Perkins-Veazie, and J. K. Collins. 2002. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. J. Food Comp. Anal. 15:309-317.

Giovannucci, E. 1999. Tomatoes, tomato-based products, lycopene, and prostate cancer: Review of the epidemiologic literature. J. Natl. Cancer Inst. 91:317-331.

Giovannucci, E., E. B. Rimm, Y. Liu, M. J. Stampfer, and W. C. Willett. 2002. A prospective study of tomato products, lycopene, and prostate cancer risk. J. Natl. Cancer Inst. 94:391-398.

Kabelka, E., W. Yang, and D. Francis. 2004. Improved tomato fruit color within an inbred backcross line derived from *Lycopersicon esuclentum* and *L. hirsutum* involves the interaction of loci. J. Amer. Soc. Hort. Sci. 129:250-257.

Kader, A. A. and M. Cantwell. 2004. Produce quality rating scales and color charts. Postharvest Horticulture Series 1-81, University of California, Davis, CA.

Kader, A. A., M. A. Stevens, M. Albright-Holton, L. L. Morris, and M. Algazi. 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. J. Amer. Soc. Hort. Sci. 102:724-731.

Lipton, W. J., 1970. Effects of high humidity and solar radiation on temperature and color of tomato fruits. J. Amer. Soc. Hort. Sci. 95:680-684.

Plotto, A. and J. Narciso. 2006. Guidelines and acceptable postharvest practices for organically grown produce. HortScience 41:287-291.

Shi, J. and M. Le Maguer. 2000. Lycopene in tomatoes: Chemical and physical properties affected by food processing. Crit. Rev. Food Sci. Nutr. 40:1-42.

Thompson, K. A., M. R. Marshall, C. I. Sims, S. A. Sargent, and J. W. Scott. 2000. Cultivar, maturity, and heat treatment on lycopene content in tomatoes. J. Food Sci. 65:791-795.

United States Department of Agriculture, Agricultural Research Service (USDA). 2005. USDA National Nutrient Database for Standard Reference, Release 18.